論文内容の要旨

論文題目：

Time-bounded Proactive Service Discovery in Ubiquitous Networks
（ユビキタスネットワーク環境における時間制約型プロアクティブサービス発見機構に関する研究）

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This dissertation describes a service discovery system that supports new application scenarios in ubiquitous networks. Traditionally, service discovery systems are used to discover network devices (for example, printers, faxes, projectors, and so on) that are available on the local area network. In contrast, we aim to develop a service discovery system that locates physical objects in the real world including objects that typically are not connected to the network. Our application scenarios include a friend finder, a discount coupon, a bargain, a goods exchange, and an exhibition. Together, these represent the future vision of service discovery in ubiquitous computing environments.

There are a number of technological solutions that can be used to achieve these application scenarios. In general, they can be divided in two categories: 1) systems that are based on infrastructure (infrastructure-based systems) and 2) systems that are not based on infrastructure (infrastructure-less systems). Systems built using cellular networks or Wi-Fi access points represent infrastructure-based solutions. Because of high network installment costs and expensive maintenance, we choose an infrastructure-less approach for our service discovery system implementation. The known wireless technologies that can be used for infrastructure-less service discovery include: Wi-Fi based Mobile Ad hoc Networks (MANET), Personal Area Networks (PAN), such as Bluetooth; and wireless sensor networks (WSN), such as Zigbee. However, these solutions are inappropriate for realizing the described scenarios because of disadvantages including uncertain or long service discovery time and high power consumption. In addition, available discovery systems based on these wireless technologies lack some tools necessary for easy device configuration. They also lack a dedicated personal wireless device for service discovery in ubiquitous computing environments. All this inspired us to develop a complete service discovery system, including software and hardware implementations, to fill the described gaps and make possible the described scenarios.

The service discovery system design depends on the selection of a communication model. Unlike previous reactive systems, in which a discovering device sends a request packet, the proposed discovery system is based on proactive discovery in which advertisers broadcast service data. The proposed model is selected because it represents a basic protocol used in almost all communication systems to obtain information about available wireless communication devices in proximity. To get such information, these devices must send periodic broadcast packets known as “beacons,” which include the device ID. In our system, we use beacons along with service data to advertise services in proximity so that other devices can receive these advertisements and filter them to check whether a user needs them or not.

In addition to a proactive discovery model, we consider a single-hop time-bounded discovery. The reason for considering a single-hop discovery is motivated by fact that multi-hop broadcasting in distributed wireless networks postulates a well-known problem called broadcast storm problem; that is, there’s a tradeoff between covered area and the number of sent re-broadcasts. In our service discovery, we need to discover—within a few dozen meters—the area that can be covered with a single-hop broadcast without generating extra traffic, which consumes power and affects scalability. Moreover, it’s important for a user to discover all services in proximity within a defined time-bound. Time-bounded discovery

allows for controlling discovery time and power consumption because a wireless device selects the lowest broadcast rate to achieve necessary discovery time-bound, thus saving more power by broadcasting fewer packets.

In practice, the realization of the pure infrastructure-less discovery system is a difficult task. This is for two reasons. First, it is difficult to achieve some fundamental functionality without using a centralized solution that would require infrastructure. For example, determining a common format data for a service requires that a server stores all data formats). Second, because we perform service discovery using miniaturized wireless devices that provide poor performance characteristics, it is convenient to use infrastructure to configure these devices for optimum performance. Hence, we propose a hybrid service discovery system that combines infrastructure-based and infrastructure-less functionalities. The distinguishing feature of the proposed system is that we require devices to discover services without relying on infrastructure. Connecting to the infrastructure is required only when configuring the device and accessing discovered services. Because these procedures take place infrequently, the proposed system is similar in its design to infrastructure-less discovery systems but provides superior performance characteristics compared to the pure infrastructure-less discovery systems. All this makes the proposed system a potential candidate for all service discovery applications in future ubiquitous networks.

In the design of our system we consider four components including a data management system, the hardware design of a miniaturized wireless discovery device, client software and wireless device firmware, and a time-bounded wireless media access control (MAC) protocol. For the design of each component, we consider conventional methods and propose new ones that best fit system requirements for flexible and efficient service discovery in ubiquitous networks.

A data management system targets three important discovery system methods: 1) a method to decide the common data format for advertisement and filter of the same service, 2) a method to achieve scalable compact data format, and 3) a procedure for handling discovered services. To achieve efficient matchmaking, we introduce a new method for data format sharing and creation that requires users to re-use available data formats or create new ones that can be shared with other users. In this case, users are guaranteed that their service data has a high chance of being discovered. In addition, we proposed a method for service data packet minimization that allows resource-constrained wireless devices to broadcast tiny service data packets that contain sufficient service information for users to locate necessary services. Having smaller data packet sizes result in shorter transfer time. This, in turn, allows for achieving superior discovery performance because the wireless channel is less busy with data traffic. Finally, we propose a data management method for handling service discoveries. In particular, we designed a method, currently not implemented in other service discovery systems, that blocks service discoveries of already discovered services.

We also implemented a hardware device prototype for proactive wireless discovery. The design requirement was to build a compact wireless device with the minimum number of low power hardware components sufficient for service discovery. In addition, it was important to make a general device that could be used in diverse discovery application scenarios without the need to develop a new device to meet application requirements. Moreover, we developed a device that allows for the replacement or extension of some hardware components should some additional hardware be needed. Finally, we include additional hardware for the device that provides a method for seamless and automatic firmware updates.

In the dissertation work, we describe the design of client software and firmware. The designed client software allows an average user to easily configure and control a wireless discovery device. The designed firmware allows a user to optimize the program size of the firmware depending on application needs. The client software includes a middleware plus generic applications developed on top of the middleware. The middleware allows a developer to access a full range of system functions to create customized applications for service discovery in ubiquitous computing environments. The generic applications allow users and developers to quickly introduce service discovery application scenarios without any need to use programming languages (unless there is a need of custom user interface). Hence, we describe our developed general web-enabled interface that lets a user configure a device for wireless discovery or advertisement, define new services, and access detailed information about discovered services. Also, we developed a unique application that lets a developer

control a wireless device with minimal development time. Finally, the dissertation describes modular firmware design that allows for minimizing the size of the firmware to make it possible to use microcontrollers with smaller available memory. Because microcontrollers with smaller program memory are cheaper, the result is a cost-effective solution. The minimization becomes possible because some application scenarios do not require the full range of available functionalities.

One component that significantly affects discovery time performance and power consumption is a wireless media access control (MAC) protocol. The dissertation describes the design and evaluation of a new wireless MAC protocol that achieves reliable and economical service advertisement given the required discovery time in a distributed wireless network. The proposed protocol achieves a given discovery time using the lowest possible transmission rates. (Low transmission rates result in lower power consumption because nodes transmit fewer packets. The protocol represents a decentralized autonomous protocol in which a node makes an autonomous decision about broadcast strategy by collecting information about network conditions. Finally, the protocol operates in a wireless distributed network that has a random topology with sparse and dense node areas.

In summary, the dissertation describes a complete solution for a service discovery in ubiquitous networks to support new application scenarios. The proposed service discovery system represents a hybrid architecture in which infrastructure-based functionalities are used only during when configuring a device or accessing discovered services. The single-hop time-bounded proactive discovery model follows the basic pattern available in most communication networks. Additionally, the proposed model can be extended to other models including reactive and/or multi-hop discovery. We review four components of the service discovery system and their specific functionality including a data management system, wireless device hardware, client software, and a wireless MAC protocol. These components include new methods, algorithms, and protocols that allow for new types of service discovery scenarios in ubiquitous computing environments.